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A SUGGESTION CONCERNING THE BOUNDARY CONDITIONS OF B STARS

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Observations of early type stars from rockets show that B stars are quite deficient in flux below λ 2400 compared with the predictions of model atmospheres.[1] It can be argued that this is an intrinsic property of the stars and not the result of an absorber between us and the star.[1] This finding has important consequences in our understanding of properties of the B stars. For example, the effective temperature of these stars must be revised downward. Although detailed understanding of these stars appears impossible at this time, we wish to make a qualitative suggestion as to the boundary conditions one might expect.

The flux is deficient in the wavelength region where B stars have been predicted to radiate most of their energy. This leads to lower bolometric luminosities than have been generally assigned to them. Now the total flux of a star is primarily determined by its mass. For an interior stellar model with a mass ten times that of the sun it has been recently shown[2] that the mass-luminosity relationship is

$$\log L = 3.4 \log m. \tag{1}$$

From the rocket observations the total luminosity must be reduced as much as a factor of two in some cases. By equation (1), this would lead to a 20 percent reduction in mass. If we assume that our knowledge of B-star masses is better than 20 percent, we must explain the discrepancy in the luminosity.

One possible method of energy dissipation is particle radiation. This has been suggested by one of us as an explanation for the overluminous secondary components of many binaries.[3] It was proposed that the extra energy was obtained through corpuscular radiation originating from the B-type primary. More recently Shklovskii[4] presented arguments to account for the λ 1300 radia-

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tion from the nebula surrounding α Virginis[5] in terms of corpuscular radiation from the star. Beta Lyrae is another case where particle radiation can be used to explain data that are otherwise inconsistent. The increase in its orbital period suggests a mass loss[6,8] greater than can be accounted for spectroscopically.[7] It is tempting to attribute at least part of the unexplained mass loss to particle radiation.

The basic difficulty in the suggestion of particle radiation in early type stars is the mechanism by which the particles would be accelerated. It is generally agreed that a magnetic field is necessary for this process, but it is difficult to see how this field would be present in a star in radiative equilibrium. A magnetic field derives its energy by hydrodynamic flow in the convective layers of a star. The high opacity that cuts off the emergent radiation below λ 2400 will also cause a steep temperature gradient, which might result in convection. If, as suggested, the absorption is due to quasi-molecules formed from various combinations of hydrogen and helium atoms and ions,[1] convection would be even more likely because the internal energy of the stellar matter would be increased by the interaction of the atoms. This is the same physical situation that leads to the formation of the convection zone in the atmosphere of the sun and other lower-temperature stars.[9] Instead of hydrogen ionization we would have in the B stars dissociation of quasi-molecules. The high opacity and a change in the ratio of specific heats could create a convective unstable state in the atmospheres of the B stars just as the ionization of hydrogen does in the solar atmosphere.[10]

The presence of a convective zone near the surface would complicate the problem of the interior of the star, depending on the actual depth of the zone. Consequently it is not clear whether or not equation (1), which is derived from the boundary conditions without convection, still holds.

We might conclude by inquiring whether or not mass dissipation by particle radiation will affect the evolution of a B star. This will be the case only if the time-scale for mass loss is such that the structure of the star will appreciably change before hydrogen burning in the convective core has been completed. If one-half the total energy is dissipated in the form of corpuscular radiation, we can estimate the mass loss Δm in a certain time in terms of the velocity of ejection, v.

Table I contains some numerical examples for a star of mass $10\ m_\odot$ with a total energy output equal to 2.45×10^3 times that of the sun. The first column gives the velocity and the second column gives the corresponding energy for protons. The third column represents the mass loss in terms of solar mass per million years. The last column represents this mass loss in equivalent number of protons per second per cm² of the stellar surface. Since the total number of atoms above the photosphere of a B0 star is 10^{23} atoms per cm², we see from the last column that the number per second per cm² from the stellar surface is not unreasonably large, even for particles of low energy.

TABLE I

RATES OF MASS LOSS OF A STAR OF 10 SOLAR MASSES IF ONE-HALF ITS ENERGY IS DISSIPATED BY ESCAPING MATTER

v	eV	Rate of Mass Dissipation	
(10^3 km/sec)	Proton	$m/10^6$ yr	H Atoms/sec/cm²
1	5.2×10^3	1.5×10	7.1×10^{20}
10	5.2×10^5	1.5×10^{-1}	7.1×10^{18}
20	2.1×10^6	3.8×10^{-2}	1.8×10^{18}
40	8.5×10^6	9.3×10^{-3}	4.4×10^{17}
80	3.5×10^7	2.2×10^{-3}	1.1×10^{17}
160	1.7×10^8	4.6×10^{-4}	2.2×10^{16}
200	3.2×10^8	2.4×10^{-4}	1.2×10^{16}
240	6.3×10^8	1.2×10^{-4}	5.9×10^{15}
270	1.2×10^9	6.4×10^{-5}	3.0×10^{15}

We may therefore conclude from Table I that the existence of particle radiation from a B star would not seriously affect the evolution of the star if the velocity of ejection is greater than 1000 km/sec.

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[1] T. P. Stecher and J. E. Milligan, *Ap. J.*, in press.

[2] S.-S. Huang, *Ap. J.*, in press.

[3] S.-S. Huang, *Pub. A.S.P.*, **70**, 473, 1958, and *Ann. d'Ap.*, 22, 527, 1959.

[4] I. S. Shklovskii, *A.J.U.S.S.R.*, **36**, 579, 1959 (*Soviet Astr.*, **3**, 569, 1960).

[5] J. E. Kupperian, Jr., A. Boggess III, and J. E. Milligan, *Ap. J.*, **128**, 453, 1958.

[6] S.-S. Huang, *A.J.*, **61**, 49, 1956.
[7] O. Struve, *Pub. A.S.P.*, **70**, 5, 1958.
[8] H. A. Abt, H. M. Jeffers, J. Gibson, and A. R. Sandage, *Ap. J.*, **135**, 429, 1962.
[9] A. Unsöld, *Physik der Sternatmosphären* (Berlin: Springer, 1955).
[10] See references in D. E. Osterbrock, *Ap. J.*, **134**, 347, 1961.

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